

University and Government Partnership in Morehead Ground System Development for Space Mission Operations

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Outline

- How partnership is formed
- Background information
- System architecture
- Operational concept
- System performance
- System validation incrementally
- What makes it works

Partnership

- Connection between MSU and DSN
 - via Lunar IceCube/Exploration Mission 1



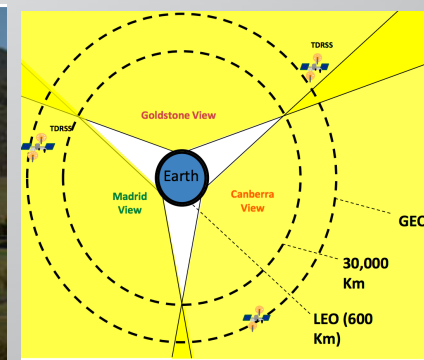
Lunar IceCube



EM-1

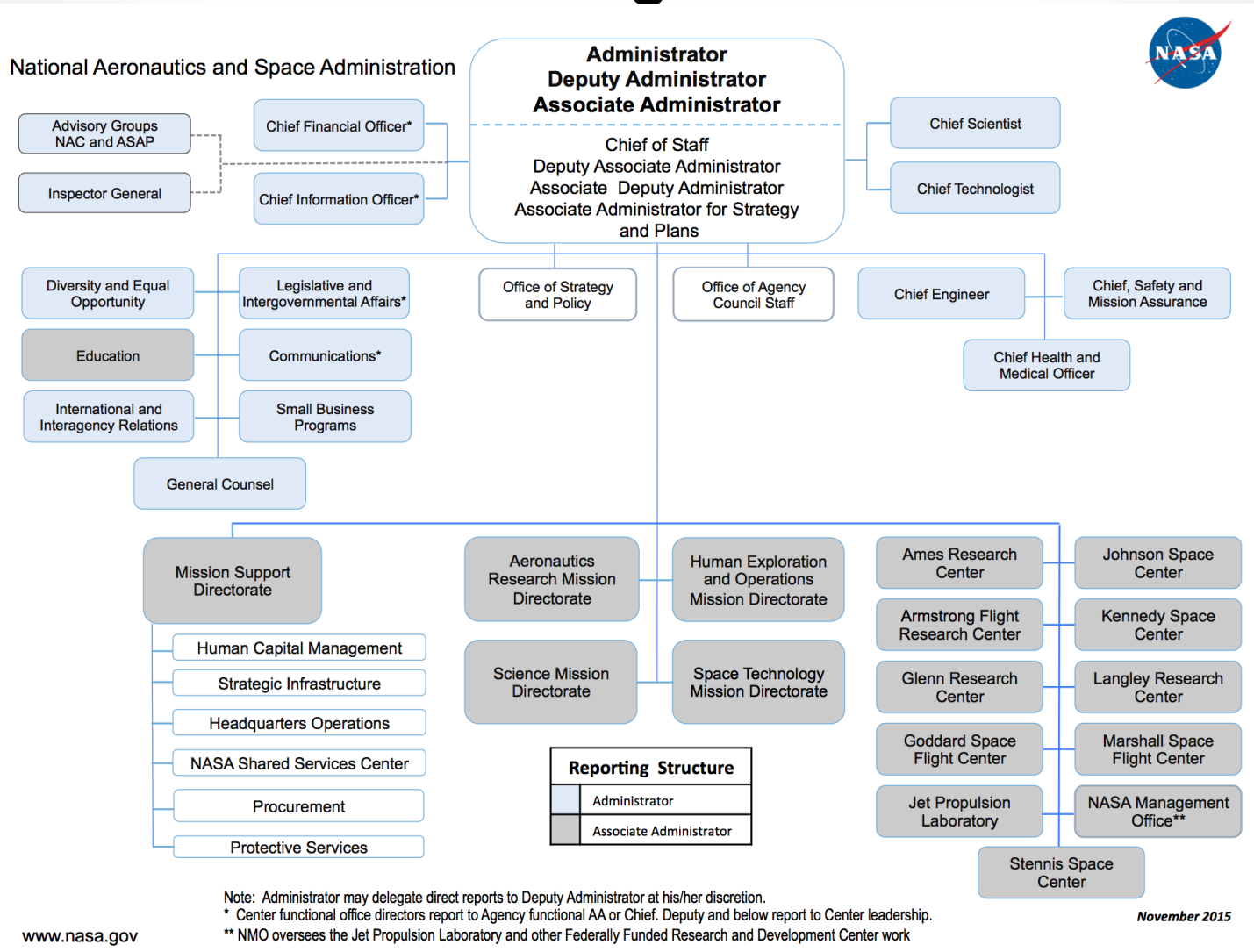


21-m MSU antenna

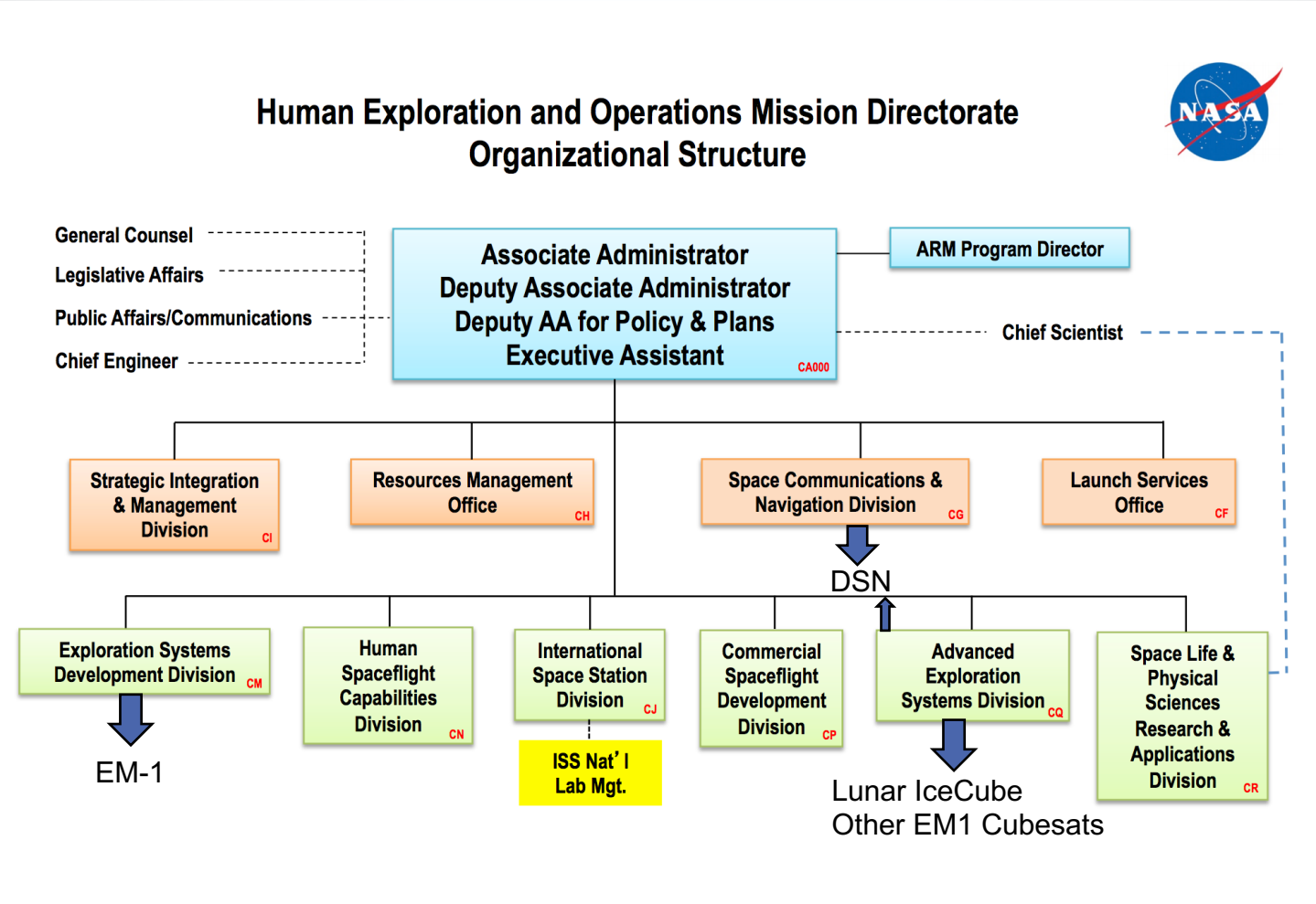


DSN antennas (34-m/70-m)

NASA Programs



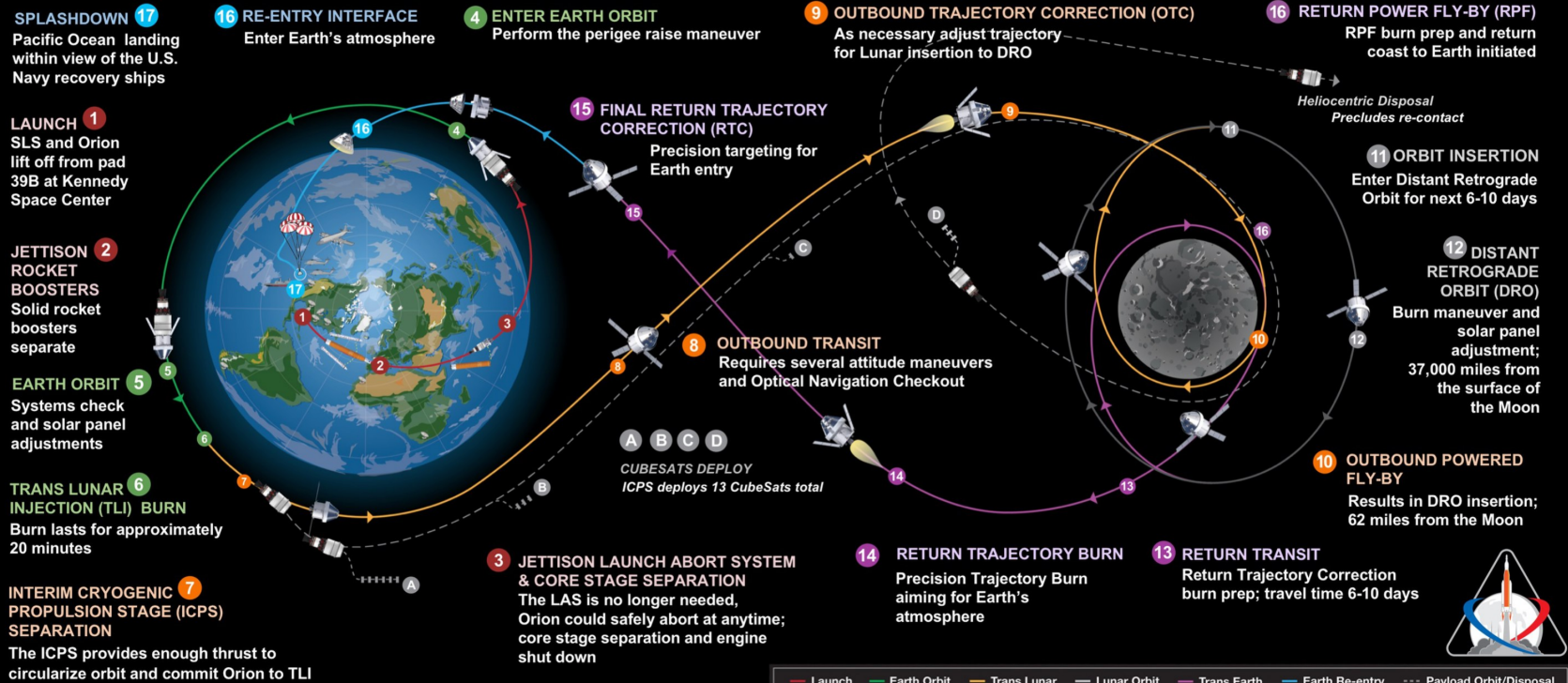
Human Exploration & Operations Mission Directorate



EM-1

EXPLORATION MISSION-1

The first uncrewed, integrated flight test of NASA's Orion spacecraft and Space Launch System rocket, launching from a modernized Kennedy spaceport



Total distance traveled: 1.3 million miles – Mission duration: 25.5 days – Re-entry speed: 24,500 mph (Mach 32) – 13 CubeSats deployed

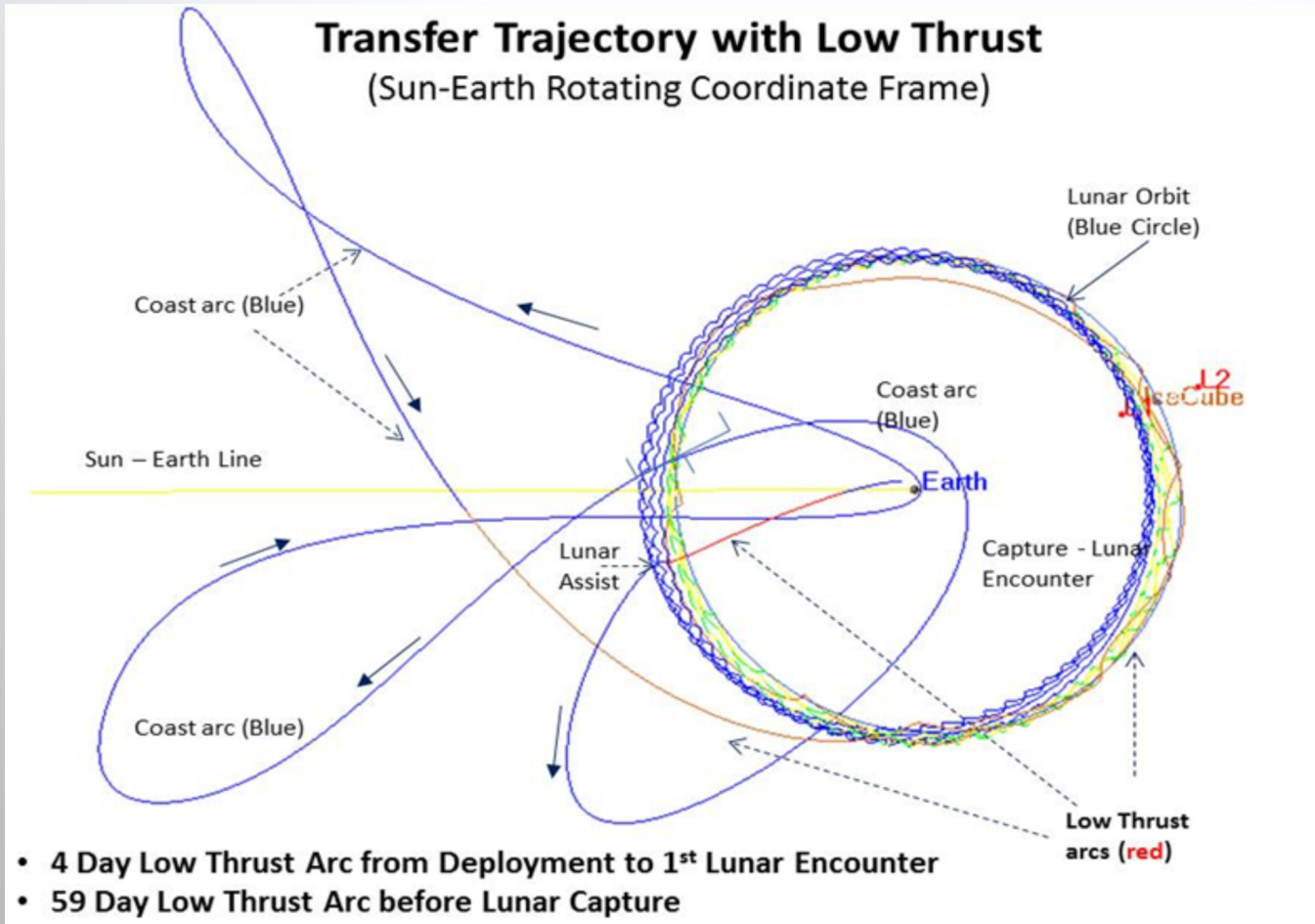
https://en.wikipedia.org/wiki/Exploration_Mission-1#/media/File:EM1-Mission-Map_Update.jpg



Jet Propulsion Laboratory
California Institute of Technology

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Lunar IceCube



Morehead State University and Goddard are partnering to create the Lunar IceCube mission shown in this artist's rendition.
Credits: Morehead State University



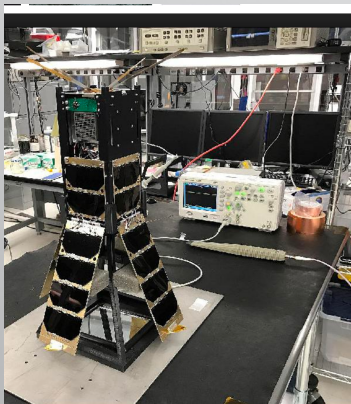
The Busek Company is developing Lunar IceCube's low-thrust electric propulsion system, the RF Ion BIT-3 thruster.
Credits: Busek Company

<https://www.nasa.gov/feature/goddard/lunar-icecube-to-take-on-big-mission-from-small-package>

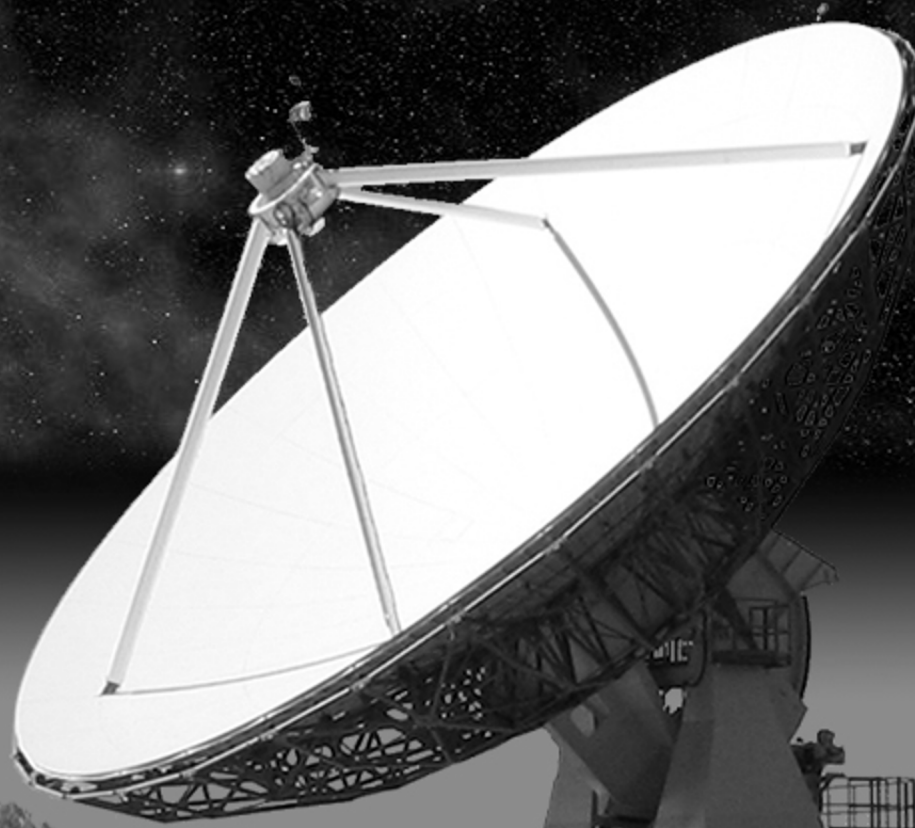
Background on MSU Capabilities

The Morehead State University Ground Station

- Relatively quiet RFI environment in eastern Kentucky
- 21-m ground station operational since 2006
 - Few in the US large enough for deep space tracking
 - Built under university funding
- Experienced RF and telecom engineers and scientists
- Experienced staff/students in mission operations
 - LRO, ISEE-3, Planet Lab, KySpace, ASTERIA



21 Meter System at Morehead



- Specifications by MSU faculty with NASA assistance
- Dual Purpose Instrument
 - Ground Station for Smallsats
 - Radio Telescope for Astronomy Research
- Funded \$3.4 M -a variety of sources- Morehead State, Federal and State Funds, KSTC, NASA
- Built and Installed by VertexRSI (General Dynamics)
- Feeds Designed and built by VertexRSI, APL, and MSU

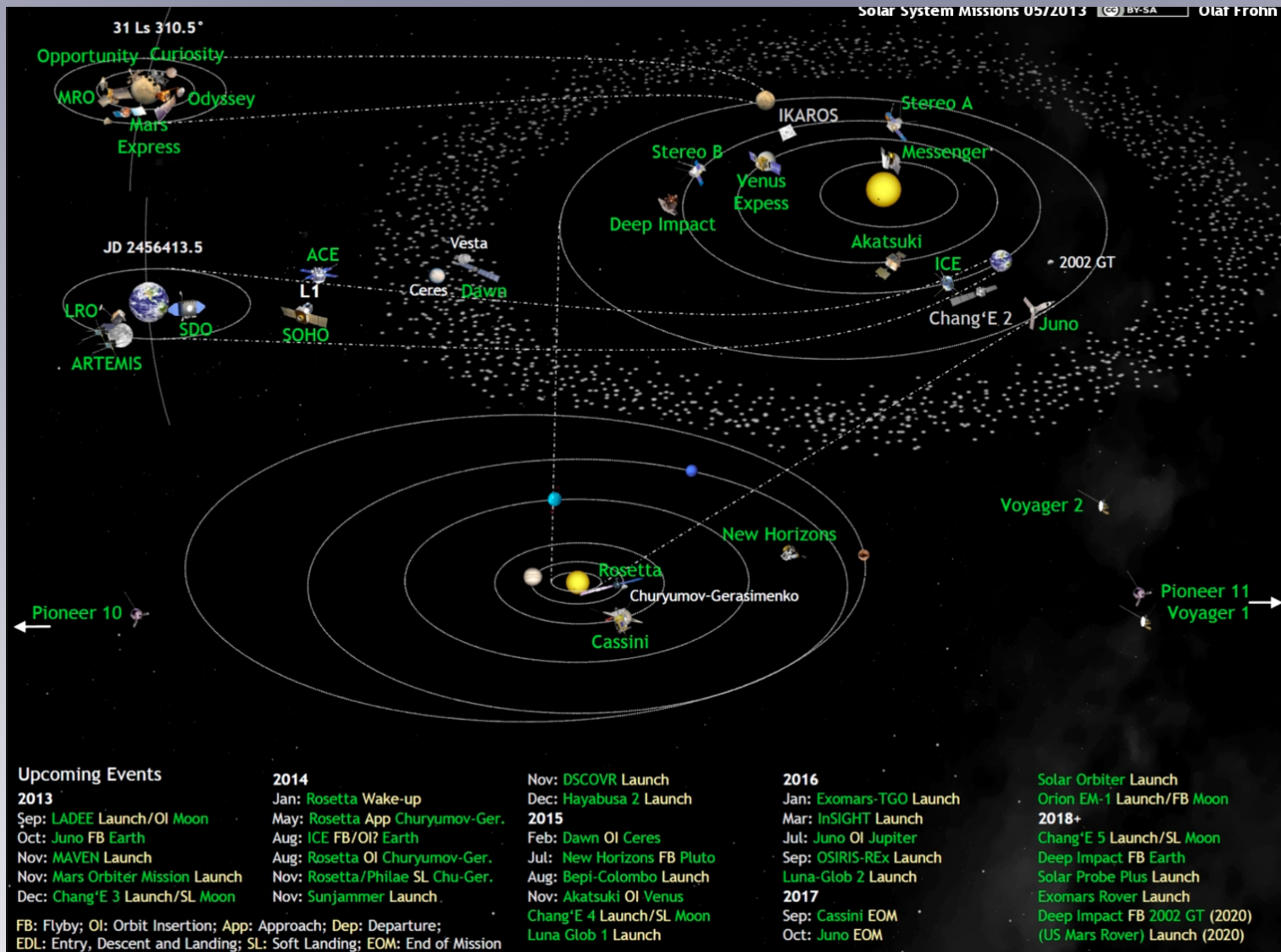
Space Projects Create Opportunities for Students



- Undergraduate Research Experiences
- Instrumentation Experience
- Engineering Design
- Observational Astrophysics Research
- Ground Ops (TT&C)
- Project Management Experience
- Systems-level Engineering Experience



Exploring spacecraft throughout Solar System



Deep Space Communications Challenges

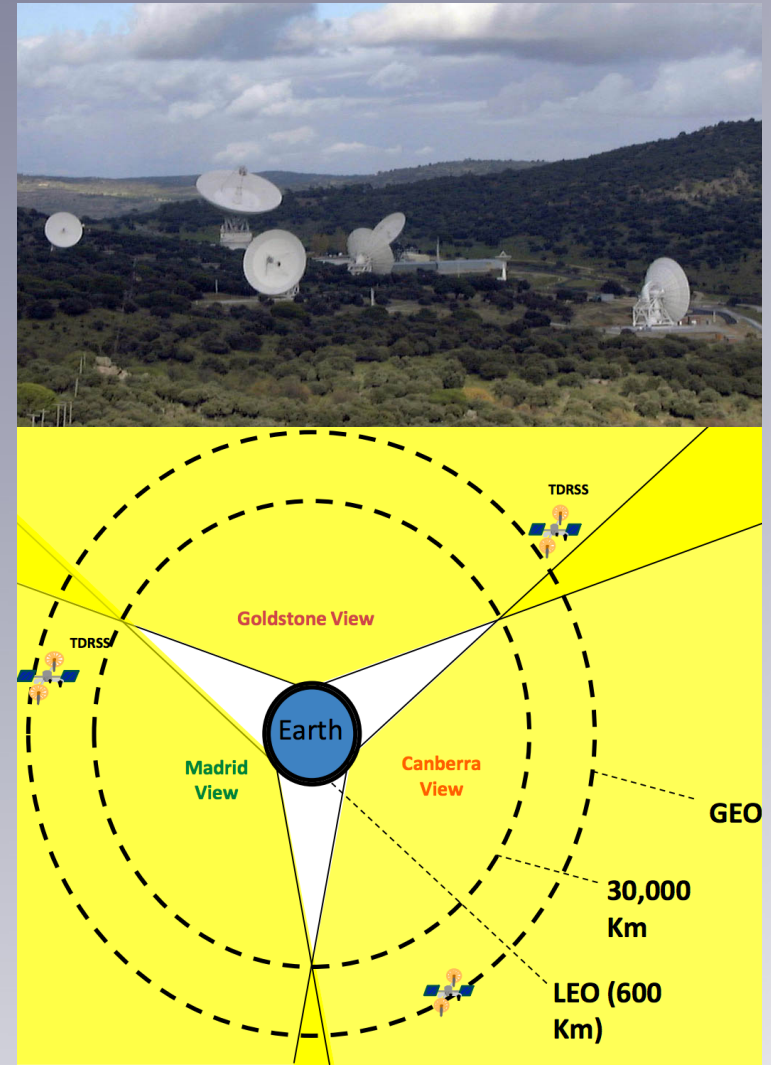
- Deep space - Interplanetary communications
 - Extended to the edge of Solar System
 - Voyager spacecraft ~130 AU
- Difference between deep space and LEO communications
 - LEO: ~1000 km
 - Deep space: ~400,000 km (0.003 AU) – 130 AU



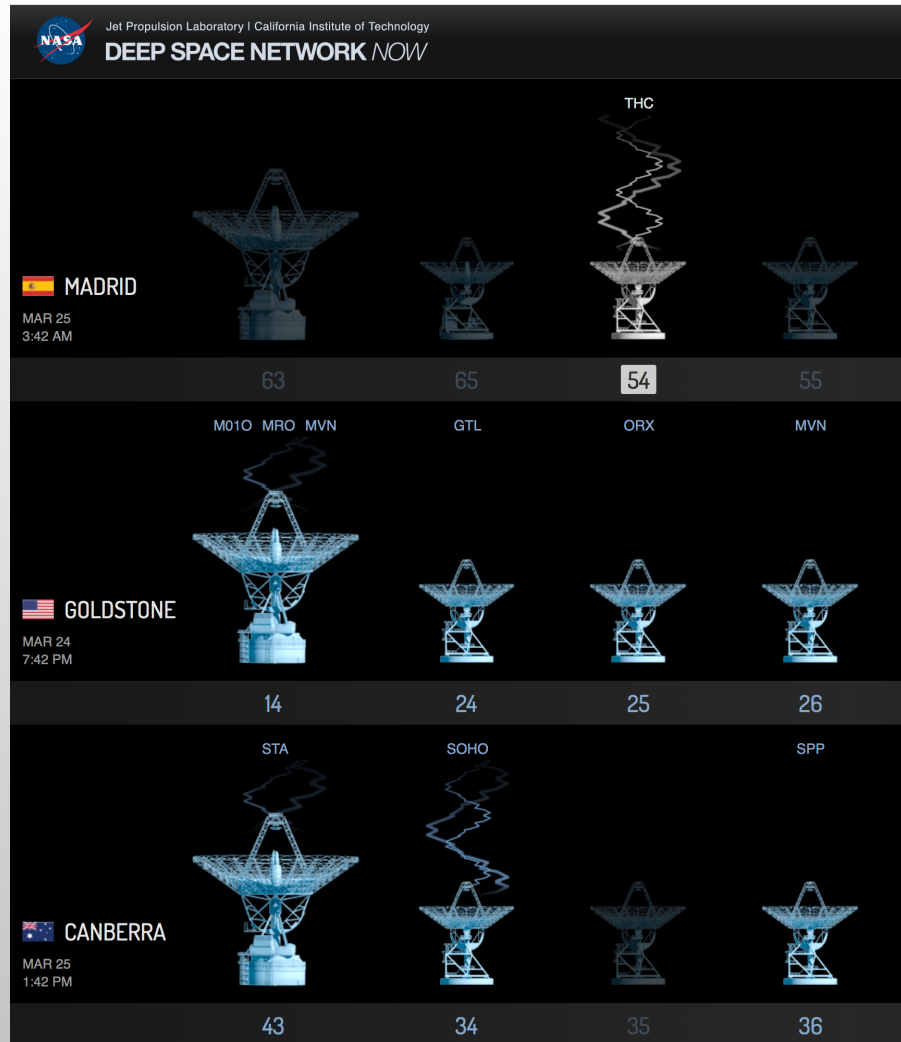
Distance	Power reduction
Moon	1.5E+05
Larange points	2.3E+06
Mars	2.3E+10
Jupiter	6.1E+11
Saturn	2.0E+12
Pluto	2.0E+13
Heliosphere	3.3E+14

NASA Deep Space Network

- Provide global coverage at 3 sites around the globe
 - One 70m and three-four 34m antennas at each site
- Support missions from HEO to edge of solar system
- Optimize high performance for deep space communications
 - Compared to typical 10m commercial tracking station
 - Lower noise (3x-6x)
 - Higher gain (10x – 50x)

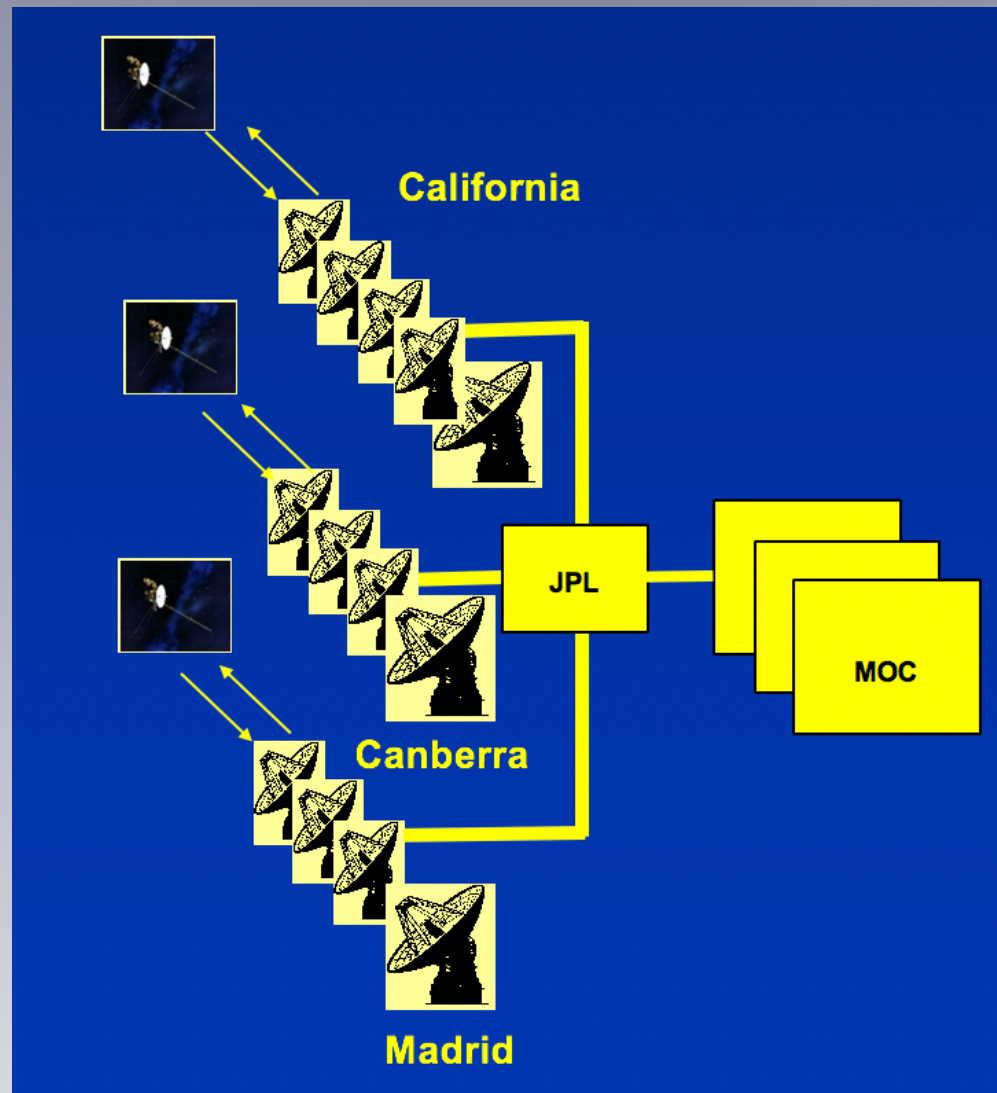


NASA Deep Space Network



<https://eyes.nasa.gov/dsn/dsn.html>

NASA Deep Space Network Architecture

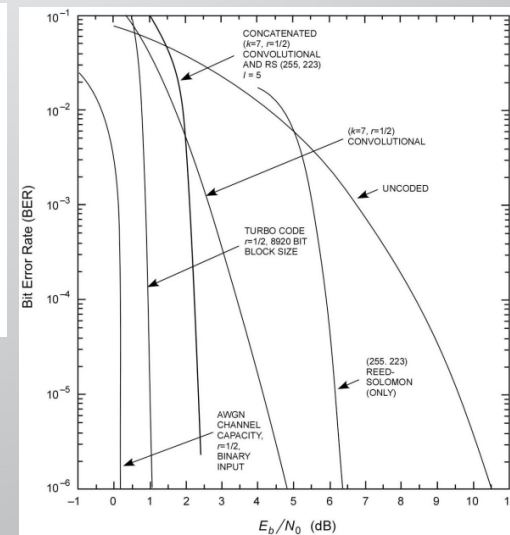
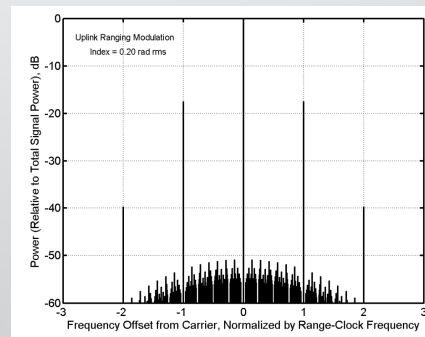
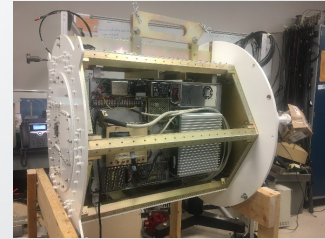


Transition from LEO to Lunar Orbit

- Distance: 1000km >> 400,000 km
 - Signal power reduction proportional to distance squared
- Require better link performance
 - Higher frequency: UHF (400 MHz) >> X-band (8 GHz)
 - Lower system noise temperature: 300K >> 100K
 - Higher perform FEC: RS >> Turbo

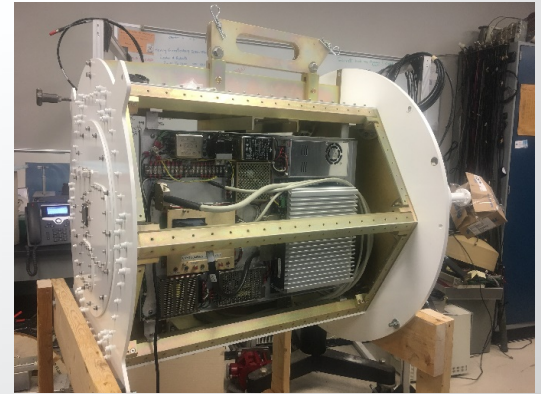
Implementation Objectives

- Upgrade MSU 21-m antenna to support Lunar IceCube and other EM-1 Cubesats
 - X-band operations
 - Deep space and near Earth
 - Full TTC functions
 - 3 kW power amplifier
 - Deep space specialization
 - Highly efficient FEC (e.g., turbo code, LDPC)
 - Pseudo-noise/sequential ranging
 - Interoperability with DSN and CCSDS compliant

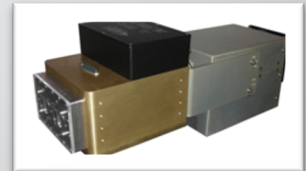


System Attributes

- Minimize implementation cost
 - Leverage on DSN-developed equipment
 - Specialized deep space signal processing for telemetry decoding and ranging
 - Adapt the already-built equipment to only necessary functions
 - Implement the rest with COTS equipment
 - New and surplus components
- Adopt common user interfaces
 - Data delivery at JPL, as with other DSN antennas
- Create opportunity for student-developed projects
 - Station monitor & control
 - System Integration and testing
 - Equipment operations



**X-band Feed
and LNA**

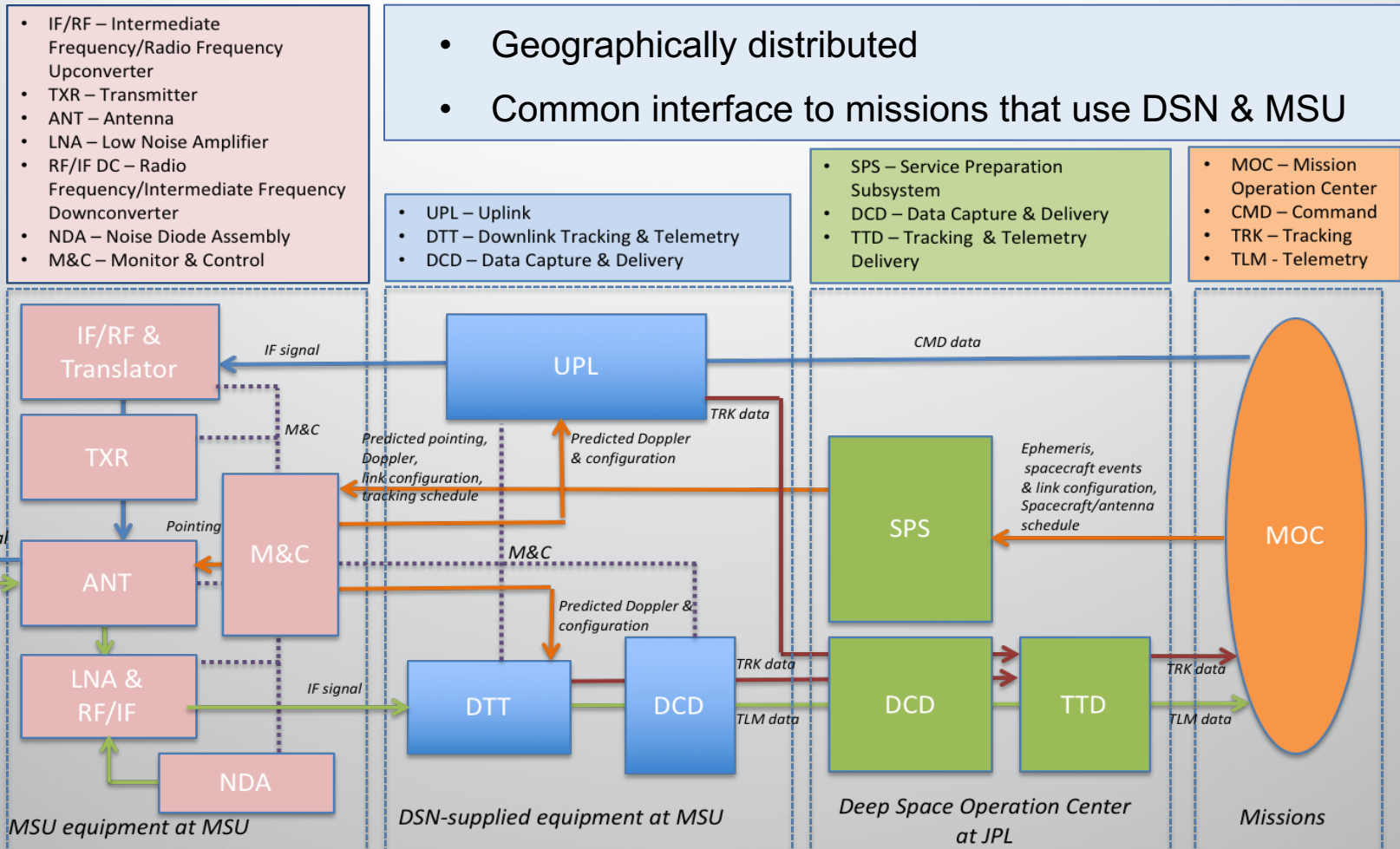


**DSN
Equipment**



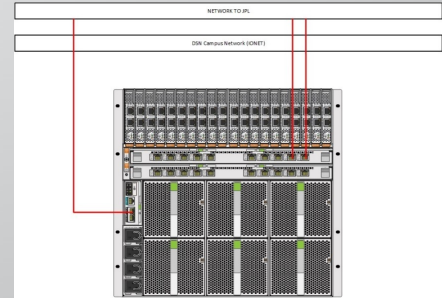
**Hydrogen
MASER**

System Architecture



Operation Concept

- Few weeks before track* {
 - Antenna scheduling via DSN
 - Transition to operational multi-mission support
 - Schedule conflict resolution
- Few days before track* {
 - Prediction data generation by DSN
 - Data retrieved by MSU
- Real-time during track* {
 - Data delivery via DSN interface points
 - Command, telemetry, radiometric data
 - WAN Connection to JPL via NASA mission backbone
 - IT security clearance by NASA
- Real-time & Post track* {
 - System monitor control and diagnostics
 - Locally controlled and archived
 - Voice network communications with MOS team



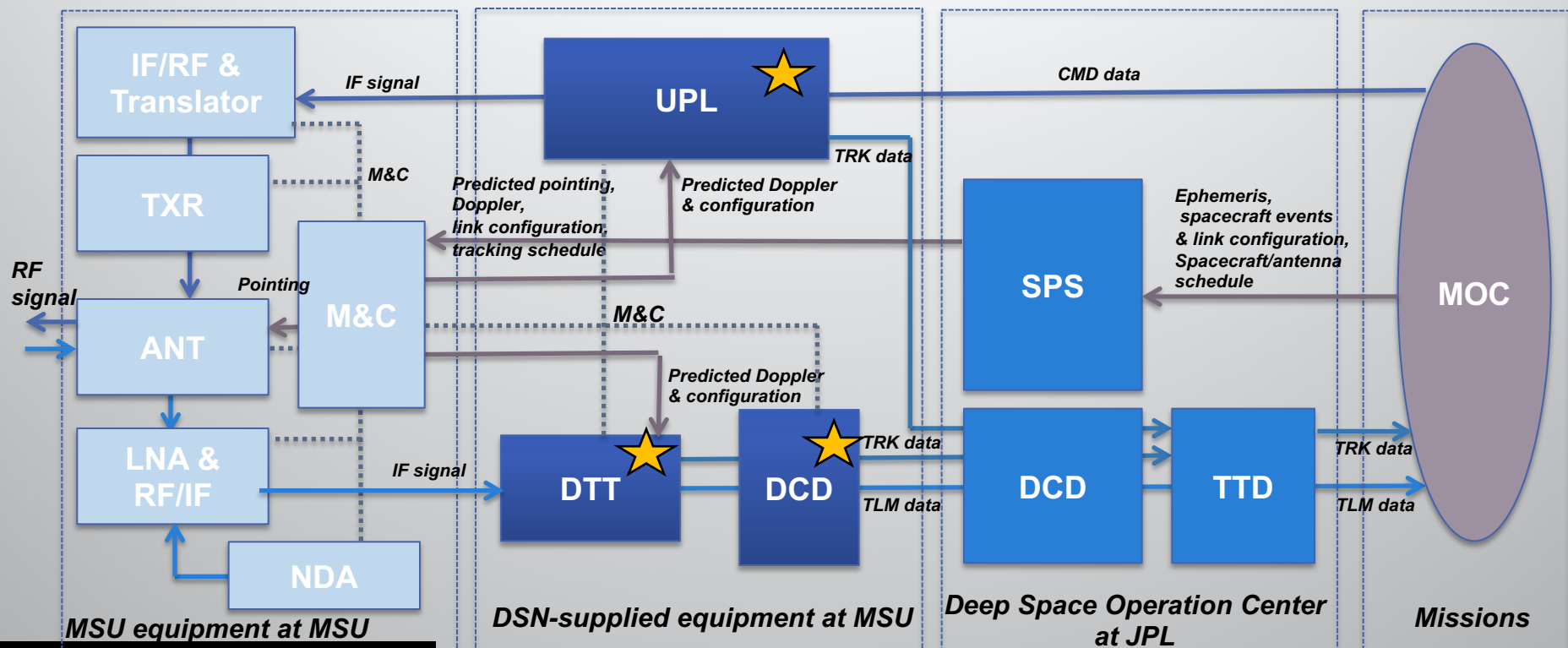
System Performance

Performance Measure	Pre-Upgrade	Post-Upgrade
X-Band Frequency Range	7.0 – 7.8 GHz	7.0 – 8.5 GHz
LNA Temperature	70 K	< 20 K
System Noise Temperature	215 K	<100 K
Antenna Gain	62 dBi (@7.7 GHz)	62.7 dBi (@8.4 GHz)
System Noise Spectral Density	-175 dBm/Hz	<-178 dBm/Hz
G/T at 5° Elevation	37.5 dB/K	40.4 dB/K
Time Standard	GPS (40 ns)	Hydrogen maser (1 ns/day)
EIRP	N/A	93.7 dBW
HPBW	0.124 deg	0.115 deg
CCSDS Compliance	N/A	Yes
Forward Error Coding	Reed Solomon/Convolutional	Reed Solomon/Convolutional, Turbo, Low Density Parity Check
Radiometric	Angle, Doppler	Angle, Doppler, Ranging

System Validation, using Internal Test Signal

First Deployment (9/2017)

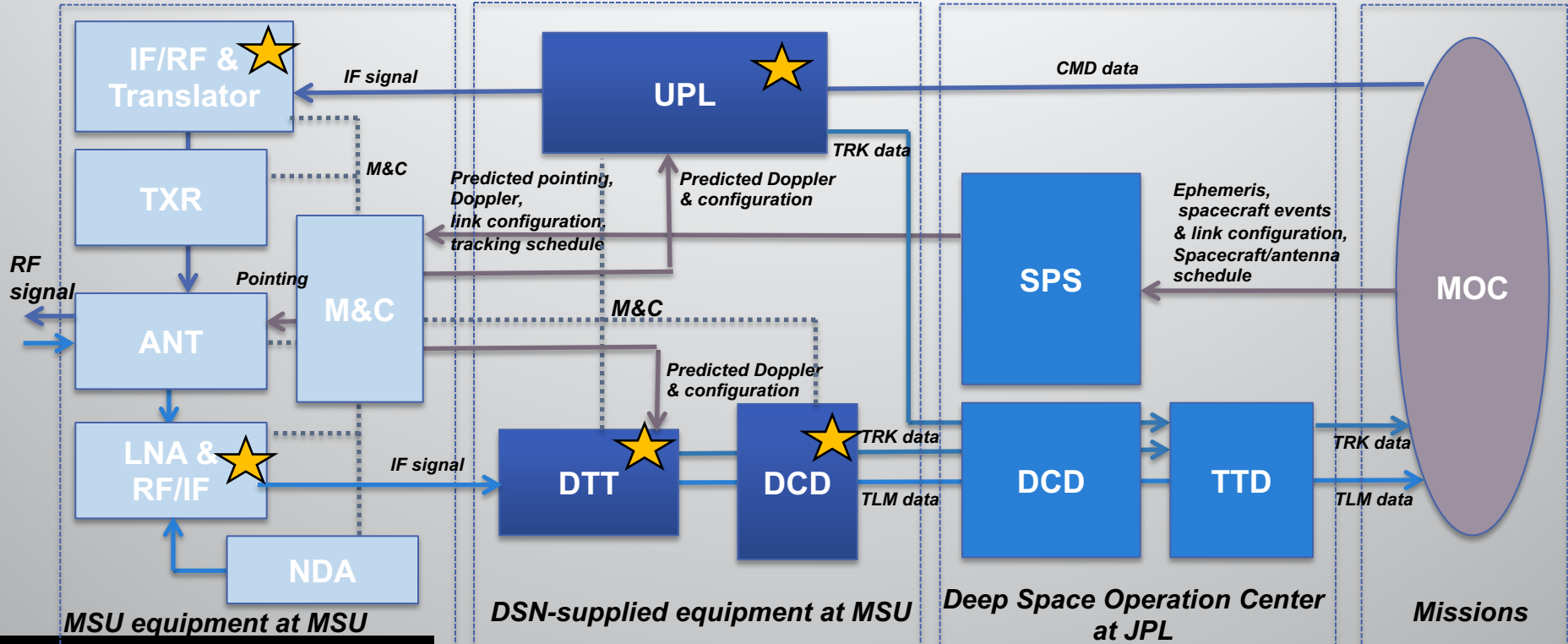
- Installed DSN equipment
- Conducted loopback tests between uplink and downlink equipment
 - Validated key TTC processing



System Validation, using Internal Test Signal with E2E flow

First Deployment (9/2017)

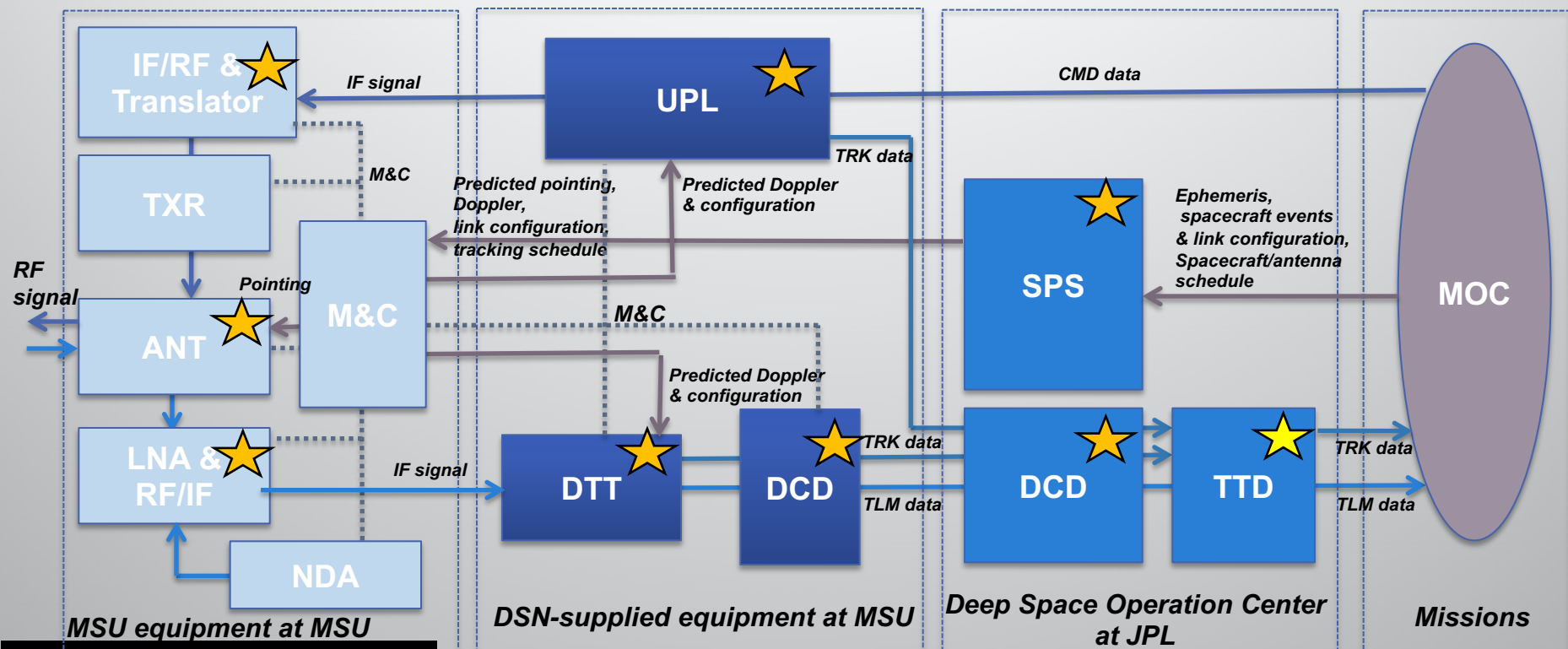
- Installed DSN equipment
- Conducted loopback tests between uplink and downlink equipment
 - Validated key TTC processing



System Validation, with spacecraft

Second Deployment (5/2018)

- Additionally installed antenna feed, LNA, RF/IF downconversion
- Conducted testing with spacecraft downlink
 - MarCO, Osiris Rex, Maven, Hayabusa2



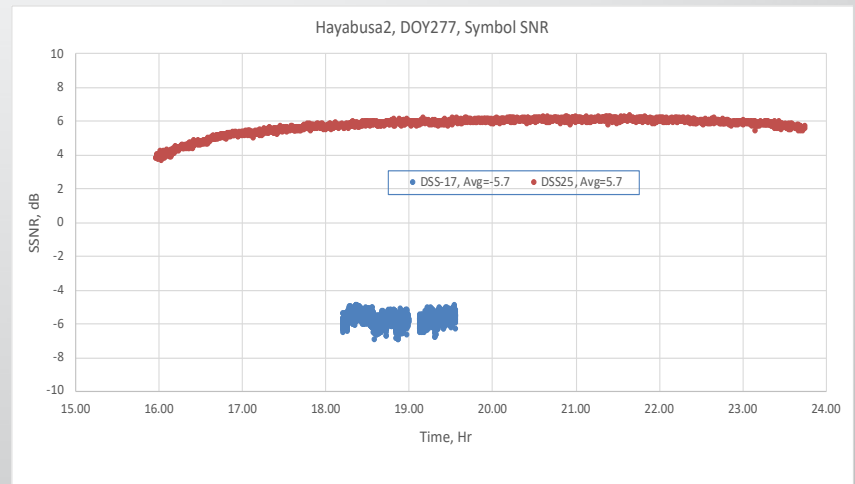
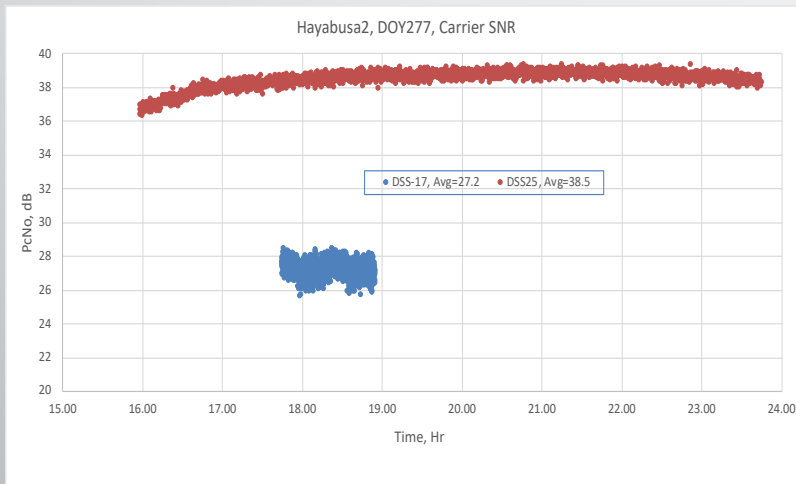
Shadow Tracking Spacecraft

Currently in progress

- Expected 10-dB G/T difference between DSN and MSU antennas
 - Antenna Gain: MSU (21m) = 0.4 * DSN (34m)
 - System Noise Temperature: MSU(100K) = 4 * DSN(25K)
- Shadow DSN tracking of missions with sufficient SNR (>10 dB link margin)
 - Hayabusa2, Osiris and Maven

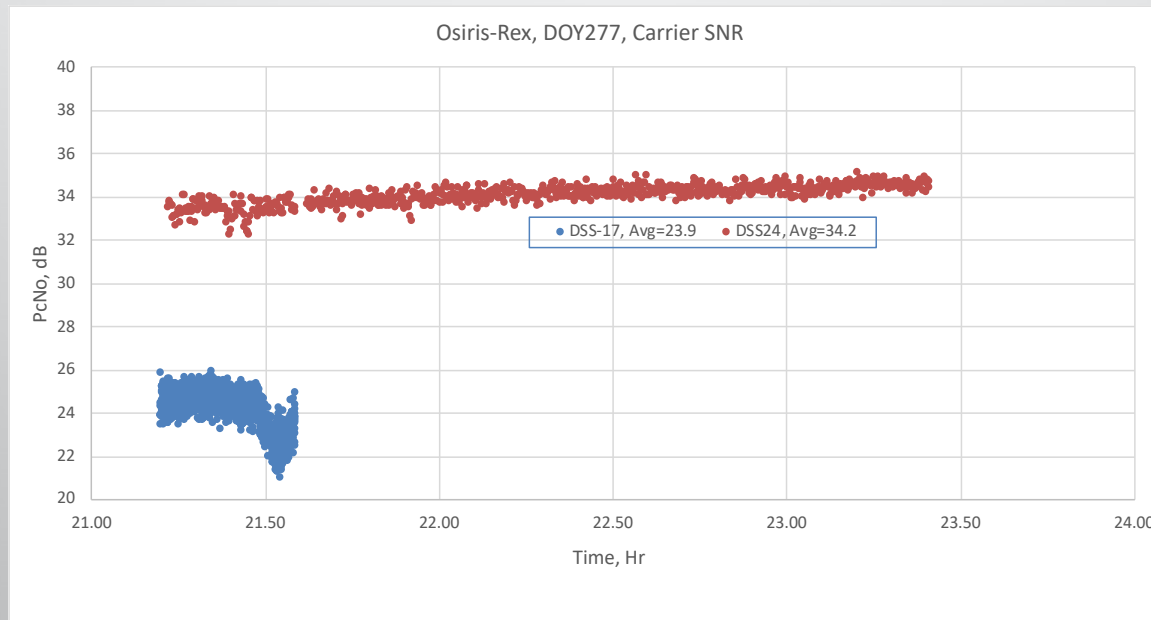
Results with Hayabusa2

- Expected signal strong enough for carrier, subcarrier and symbol locks
 - Not strong enough for telemetry decoded
- Observed 11.3 dB difference between MSU and DSN antennas, based on carrier SNR and symbol SNR
 - Within bounds of 10 dB expectation



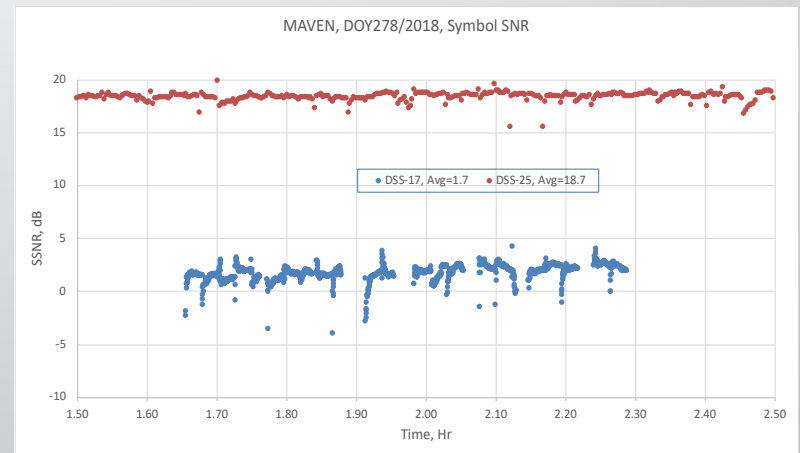
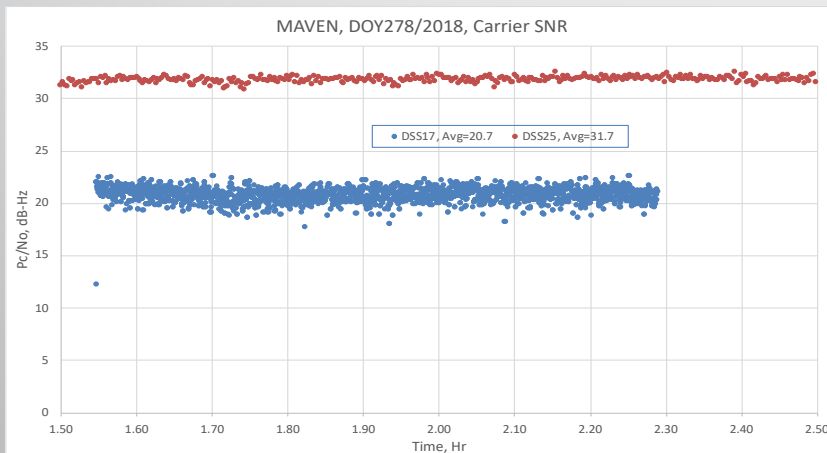
Results with Osiris

- Expected signal strong enough for carrier, subcarrier and symbol locks
 - Insufficient bit SNR (E_b/N_0) for telemetry frame decoding
- Observed
 - Achieved carrier lock, but not subcarrier nor symbol locks
 - 10.3 dB difference between MSU and DSN antennas
 - Consistent with expectation



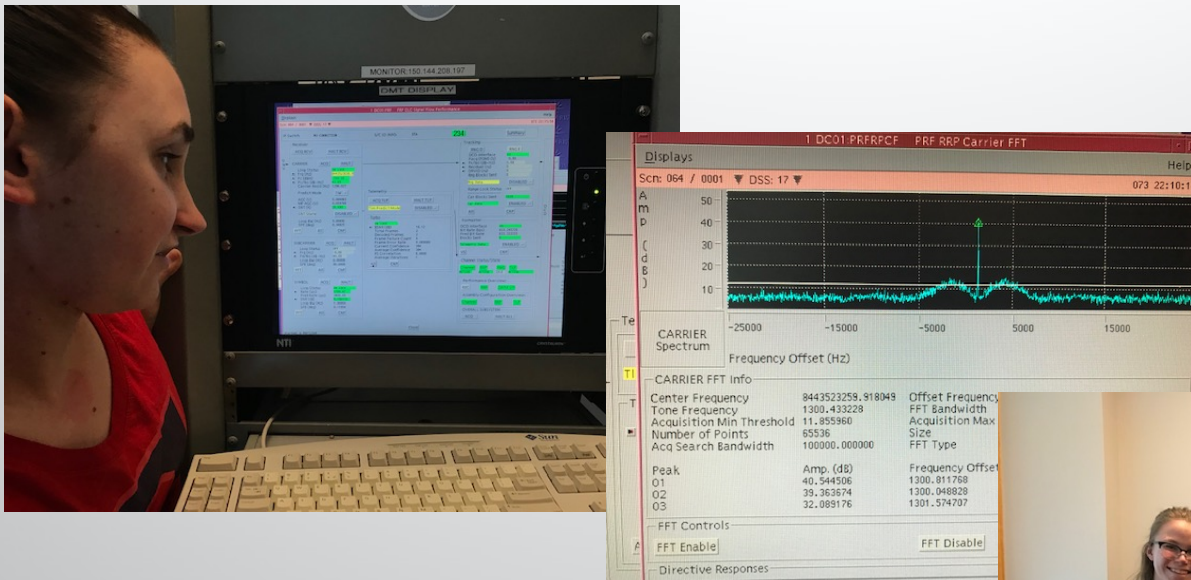
Results with MAVEN

- Expected signal strong enough for carrier, subcarrier and symbol locks and telemetry decoded
- Observed
 - Carrier lock - 11.0 dB difference between MSU and DSN antennas
 - Subcarrier lock – Not achieved
 - Symbol lock – 17 dB difference, due to lack of subcarrier lock
 - Telemetry decode – Not achieved, due to lack of subcarrier lock



Recent results with Osiris & Stereo

- Success!!!
 - Fully decoded telemetry data



What makes it works

- AES programmatic support
- Staff & students expertise
 - Previous Cubesat operations
 - Core engineering staff with RF experiences
 - Small focused team
- Ownership of system
 - Shared responsibilities
- Available funding support